US009472219B1

(12) **United States Patent**
**Raghunathan**

(10) **Patent No.: US 9,472,219 B1**
(45) **Date of Patent: Oct. 18, 2016**

(54) **DATA STORAGE DEVICE CALIBRATING PARAMETER FOR HEAT ASSISTED MAGNETIC RECORDING**

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( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/736,860**

(22) Filed: **Jun. 11, 2015**

**Related U.S. Application Data**

(60) Provisional application No. 62/156,136, filed on May 1, 2015.

(51) **Int. Cl.**

| | |
|---|---|
| ***G11B 11/00*** | (2006.01) |
| ***G11B 13/04*** | (2006.01) |
| ***G11B 5/48*** | (2006.01) |
| ***G11B 20/10*** | (2006.01) |
| ***G11B 5/60*** | (2006.01) |
| *G11B 5/00* | (2006.01) |

(52) **U.S. Cl.**
CPC ........... ***G11B 5/4866*** (2013.01); ***G11B 5/6011*** (2013.01); ***G11B 5/6029*** (2013.01); ***G11B 5/6076*** (2013.01); ***G11B 20/10388*** (2013.01); *G11B 2005/0021* (2013.01)

(58) **Field of Classification Search**
CPC .......... G11B 2005/0021; G11B 5/607; G11B 5/6076; G11B 7/1267; G11B 13/04; G11B 2005/001; G11B 5/02; G11B 5/455; G11B 5/6029; G11B 5/6064; G11B 2007/0013; G11B 21/003; G11B 5/6011
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| 6,018,789 | A | 1/2000 | Sokolov et al. |
| 6,065,095 | A | 5/2000 | Sokolov et al. |
| 6,078,452 | A | 6/2000 | Kittilson et al. |
| 6,081,447 | A | 6/2000 | Lofgren et al. |
| 6,092,149 | A | 7/2000 | Hicken et al. |
| 6,092,150 | A | 7/2000 | Sokolov et al. |
| 6,094,707 | A | 7/2000 | Sokolov et al. |
| 6,105,104 | A | 8/2000 | Guttmann et al. |
| 6,111,717 | A | 8/2000 | Cloke et al. |
| 6,145,052 | A | 11/2000 | Howe et al. |
| 6,175,893 | B1 | 1/2001 | D'Souza et al. |
| 6,178,056 | B1 | 1/2001 | Cloke et al. |
| 6,191,909 | B1 | 2/2001 | Cloke et al. |

(Continued)

OTHER PUBLICATIONS

Phillip Scott Haralson, et al., U.S. Appl. No. 14/754,340, filed Jun. 29, 2015, 32 pages.

(Continued)

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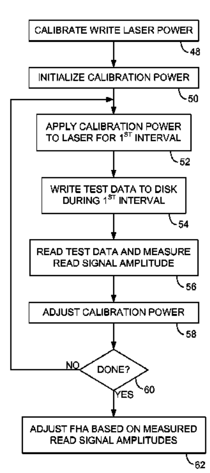
(57) **ABSTRACT**

A data storage device is disclosed comprising a head actuated over a disk, wherein the head comprises a laser configured to heat the disk while writing data to the disk. A write power for the laser is calibrated, wherein the write power is applied to the laser while writing user data to the disk. A calibration power is applied to the laser for a first interval, wherein the calibration power is high enough to cause the head to contact the disk if applied for a second interval longer than the first interval. While applying the calibration power to the laser, test data is written to the disk during at least part of the first interval. The test data is read from the disk to generate a read signal, and a metric is generated based on the read signal.

**14 Claims, 4 Drawing Sheets**



(56) **References Cited**

U.S. PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| 6,195,218 | B1 | 2/2001 | Guttmann et al. |
| 6,205,494 | B1 | 3/2001 | Williams |
| 6,208,477 | B1 | 3/2001 | Cloke et al. |
| 6,223,303 | B1 | 4/2001 | Billings et al. |
| 6,230,233 | B1 | 5/2001 | Lofgren et al. |
| 6,246,346 | B1 | 6/2001 | Cloke et al. |
| 6,249,393 | B1 | 6/2001 | Billings et al. |
| 6,256,695 | B1 | 7/2001 | Williams |
| 6,262,857 | B1 | 7/2001 | Hull et al. |
| 6,263,459 | B1 | 7/2001 | Schibilla |
| 6,272,694 | B1 | 8/2001 | Weaver et al. |
| 6,278,568 | B1 | 8/2001 | Cloke et al. |
| 6,279,089 | B1 | 8/2001 | Schibilla et al. |
| 6,289,484 | B1 | 9/2001 | Rothberg et al. |
| 6,292,912 | B1 | 9/2001 | Cloke et al. |
| 6,310,740 | B1 | 10/2001 | Dunbar et al. |
| 6,317,850 | B1 | 11/2001 | Rothberg |
| 6,327,106 | B1 | 12/2001 | Rothberg |
| 6,337,778 | B1 | 1/2002 | Gagne |
| 6,369,969 | B1 | 4/2002 | Christiansen et al. |
| 6,384,999 | B1 | 5/2002 | Schibilla |
| 6,388,833 | B1 | 5/2002 | Golowka et al. |
| 6,405,342 | B1 | 6/2002 | Lee |
| 6,408,357 | B1 | 6/2002 | Hanmann et al. |
| 6,408,406 | B1 | 6/2002 | Parris |
| 6,411,452 | B1 | 6/2002 | Cloke |
| 6,411,458 | B1 | 6/2002 | Billings et al. |
| 6,412,083 | B1 | 6/2002 | Rothberg et al. |
| 6,415,349 | B1 | 7/2002 | Hull et al. |
| 6,425,128 | B1 | 7/2002 | Krapf et al. |
| 6,441,981 | B1 | 8/2002 | Cloke et al. |
| 6,442,328 | B1 | 8/2002 | Elliott et al. |
| 6,445,524 | B1 | 9/2002 | Nazarian et al. |
| 6,449,767 | B1 | 9/2002 | Krapf et al. |
| 6,453,115 | B1 | 9/2002 | Boyle |
| 6,470,420 | B1 | 10/2002 | Hospodor |
| 6,480,020 | B1 | 11/2002 | Jung et al. |
| 6,480,349 | B1 | 11/2002 | Kim et al. |
| 6,480,932 | B1 | 11/2002 | Vallis et al. |
| 6,483,986 | B1 | 11/2002 | Krapf |
| 6,487,032 | B1 | 11/2002 | Cloke et al. |
| 6,490,635 | B1 | 12/2002 | Holmes |
| 6,493,173 | B1 | 12/2002 | Kim et al. |
| 6,499,083 | B1 | 12/2002 | Hamlin |
| 6,519,104 | B1 | 2/2003 | Cloke et al. |
| 6,525,892 | B1 | 2/2003 | Dunbar et al. |
| 6,545,830 | B1 | 4/2003 | Briggs et al. |
| 6,546,489 | B1 | 4/2003 | Frank, Jr. et al. |
| 6,550,021 | B1 | 4/2003 | Dalphy et al. |
| 6,552,880 | B1 | 4/2003 | Dunbar et al. |
| 6,553,457 | B1 | 4/2003 | Wilkins et al. |
| 6,578,106 | B1 | 6/2003 | Price |
| 6,580,573 | B1 | 6/2003 | Hull et al. |
| 6,594,183 | B1 | 7/2003 | Lofgren et al. |
| 6,600,620 | B1 | 7/2003 | Krounbi et al. |
| 6,601,137 | B1 | 7/2003 | Castro et al. |
| 6,603,622 | B1 | 8/2003 | Christiansen et al. |
| 6,603,625 | B1 | 8/2003 | Hospodor et al. |
| 6,604,220 | B1 | 8/2003 | Lee |
| 6,606,682 | B1 | 8/2003 | Dang et al. |
| 6,606,714 | B1 | 8/2003 | Thelin |
| 6,606,717 | B1 | 8/2003 | Yu et al. |
| 6,611,393 | B1 | 8/2003 | Nguyen et al. |
| 6,615,312 | B1 | 9/2003 | Hamlin et al. |
| 6,639,748 | B1 | 10/2003 | Christiansen et al. |
| 6,647,481 | B1 | 11/2003 | Luu et al. |
| 6,654,193 | B1 | 11/2003 | Thelin |
| 6,657,810 | B1 | 12/2003 | Kupferman |
| 6,661,591 | B1 | 12/2003 | Rothberg |
| 6,665,772 | B1 | 12/2003 | Hamlin |
| 6,687,073 | B1 | 2/2004 | Kupferman |
| 6,687,078 | B1 | 2/2004 | Kim |
| 6,687,850 | B1 | 2/2004 | Rothberg |
| 6,690,523 | B1 | 2/2004 | Nguyen et al. |
| 6,690,882 | B1 | 2/2004 | Hanmann et al. |
| 6,691,198 | B1 | 2/2004 | Hamlin |
| 6,691,213 | B1 | 2/2004 | Luu et al. |
| 6,691,255 | B1 | 2/2004 | Rothberg et al. |
| 6,693,760 | B1 | 2/2004 | Krounbi et al. |
| 6,694,477 | B1 | 2/2004 | Lee |
| 6,697,914 | B1 | 2/2004 | Hospodor et al. |
| 6,704,153 | B1 | 3/2004 | Rothberg et al. |
| 6,708,251 | B1 | 3/2004 | Boyle et al. |
| 6,710,951 | B1 | 3/2004 | Cloke |
| 6,711,628 | B1 | 3/2004 | Thelin |
| 6,711,635 | B1 | 3/2004 | Wang |
| 6,711,660 | B1 | 3/2004 | Milne et al. |
| 6,715,044 | B2 | 3/2004 | Lofgren et al. |
| 6,724,982 | B1 | 4/2004 | Hamlin |
| 6,725,329 | B1 | 4/2004 | Ng et al. |
| 6,735,650 | B1 | 5/2004 | Rothberg |
| 6,735,693 | B1 | 5/2004 | Hamlin |
| 6,744,772 | B1 | 6/2004 | Eneboe et al. |
| 6,745,283 | B1 | 6/2004 | Dang |
| 6,751,402 | B1 | 6/2004 | Elliott et al. |
| 6,757,481 | B1 | 6/2004 | Nazarian et al. |
| 6,772,281 | B2 | 8/2004 | Hamlin |
| 6,781,826 | B1 | 8/2004 | Goldstone et al. |
| 6,782,449 | B1 | 8/2004 | Codilian et al. |
| 6,791,779 | B1 | 9/2004 | Singh et al. |
| 6,792,486 | B1 | 9/2004 | Hanan et al. |
| 6,799,274 | B1 | 9/2004 | Hamlin |
| 6,811,427 | B2 | 11/2004 | Garrett et al. |
| 6,826,003 | B1 | 11/2004 | Subrahmanyam |
| 6,826,614 | B1 | 11/2004 | Hanmann et al. |
| 6,832,041 | B1 | 12/2004 | Boyle |
| 6,832,929 | B2 | 12/2004 | Garrett et al. |
| 6,845,405 | B1 | 1/2005 | Thelin |
| 6,845,427 | B1 | 1/2005 | Atai-Azimi |
| 6,850,443 | B2 | 2/2005 | Lofgren et al. |
| 6,851,055 | B1 | 2/2005 | Boyle et al. |
| 6,851,063 | B1 | 2/2005 | Boyle et al. |
| 6,853,731 | B1 | 2/2005 | Boyle et al. |
| 6,854,022 | B1 | 2/2005 | Thelin |
| 6,862,660 | B1 | 3/2005 | Wilkins et al. |
| 6,880,043 | B1 | 4/2005 | Castro et al. |
| 6,882,486 | B1 | 4/2005 | Kupferman |
| 6,884,085 | B1 | 4/2005 | Goldstone |
| 6,888,831 | B1 | 5/2005 | Hospodor et al. |
| 6,892,217 | B1 | 5/2005 | Hanmann et al. |
| 6,892,249 | B1 | 5/2005 | Codilian et al. |
| 6,892,313 | B1 | 5/2005 | Codilian et al. |
| 6,895,455 | B1 | 5/2005 | Rothberg |
| 6,895,500 | B1 | 5/2005 | Rothberg |
| 6,898,730 | B1 | 5/2005 | Hanan |
| 6,910,099 | B1 | 6/2005 | Wang et al. |
| 6,928,470 | B1 | 8/2005 | Hamlin |
| 6,931,439 | B1 | 8/2005 | Hanmann et al. |
| 6,934,104 | B1 | 8/2005 | Kupferman |
| 6,934,713 | B2 | 8/2005 | Schwartz et al. |
| 6,940,873 | B2 | 9/2005 | Boyle et al. |
| 6,943,978 | B1 | 9/2005 | Lee |
| 6,948,165 | B1 | 9/2005 | Luu et al. |
| 6,950,260 | B2 | 9/2005 | Coffey et al. |
| 6,950,267 | B1 | 9/2005 | Liu et al. |
| 6,954,733 | B1 | 10/2005 | Ellis et al. |
| 6,961,814 | B1 | 11/2005 | Thelin et al. |
| 6,965,489 | B1 | 11/2005 | Lee et al. |
| 6,965,563 | B1 | 11/2005 | Hospodor et al. |
| 6,965,966 | B1 | 11/2005 | Rothberg et al. |
| 6,967,799 | B1 | 11/2005 | Lee |
| 6,968,422 | B1 | 11/2005 | Codilian et al. |
| 6,968,450 | B1 | 11/2005 | Rothberg et al. |
| 6,973,495 | B1 | 12/2005 | Milne et al. |
| 6,973,570 | B1 | 12/2005 | Hamlin |
| 6,975,472 | B2 | 12/2005 | Stover et al. |
| 6,976,190 | B1 | 12/2005 | Goldstone |
| 6,983,316 | B1 | 1/2006 | Milne et al. |
| 6,986,007 | B1 | 1/2006 | Procyk et al. |
| 6,986,154 | B1 | 1/2006 | Price et al. |
| 6,995,933 | B1 | 2/2006 | Codilian et al. |
| 6,996,501 | B1 | 2/2006 | Rothberg |
| 6,996,669 | B1 | 2/2006 | Dang et al. |
| 7,002,926 | B1 | 2/2006 | Eneboe et al. |

(56) **References Cited**

U.S. PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| 7,003,674 | B1 | 2/2006 | Hamlin |
| 7,006,316 | B1 | 2/2006 | Sargenti, Jr. et al. |
| 7,009,820 | B1 | 3/2006 | Hogg |
| 7,023,639 | B1 | 4/2006 | Kupferman |
| 7,024,491 | B1 | 4/2006 | Hanmann et al. |
| 7,024,549 | B1 | 4/2006 | Luu et al. |
| 7,024,614 | B1 | 4/2006 | Thelin et al. |
| 7,027,242 | B1 | 4/2006 | Terrill et al. |
| 7,027,716 | B1 | 4/2006 | Boyle et al. |
| 7,028,174 | B1 | 4/2006 | Atai-Azimi et al. |
| 7,031,902 | B1 | 4/2006 | Catiller |
| 7,046,465 | B1 | 5/2006 | Kupferman |
| 7,046,488 | B1 | 5/2006 | Hogg |
| 7,050,252 | B1 | 5/2006 | Vallis |
| 7,054,937 | B1 | 5/2006 | Milne et al. |
| 7,055,000 | B1 | 5/2006 | Severtson |
| 7,055,167 | B1 | 5/2006 | Masters |
| 7,057,836 | B1 | 6/2006 | Kupferman |
| 7,062,398 | B1 | 6/2006 | Rothberg |
| 7,075,746 | B1 | 7/2006 | Kupferman |
| 7,076,604 | B1 | 7/2006 | Thelin |
| 7,082,494 | B1 | 7/2006 | Thelin et al. |
| 7,088,538 | B1 | 8/2006 | Codilian et al. |
| 7,088,545 | B1 | 8/2006 | Singh et al. |
| 7,092,186 | B1 | 8/2006 | Hogg |
| 7,095,577 | B1 | 8/2006 | Codilian et al. |
| 7,099,095 | B1 | 8/2006 | Subrahmanyam et al. |
| 7,099,097 | B2 | 8/2006 | Hamaguchi et al. |
| 7,106,537 | B1 | 9/2006 | Bennett |
| 7,106,947 | B2 | 9/2006 | Boyle et al. |
| 7,110,202 | B1 | 9/2006 | Vasquez |
| 7,111,116 | B1 | 9/2006 | Boyle et al. |
| 7,114,029 | B1 | 9/2006 | Thelin |
| 7,120,737 | B1 | 10/2006 | Thelin |
| 7,120,806 | B1 | 10/2006 | Codilian et al. |
| 7,126,776 | B1 | 10/2006 | Warren, Jr. et al. |
| 7,129,763 | B1 | 10/2006 | Bennett et al. |
| 7,133,600 | B1 | 11/2006 | Boyle |
| 7,136,244 | B1 | 11/2006 | Rothberg |
| 7,146,094 | B1 | 12/2006 | Boyle |
| 7,149,046 | B1 | 12/2006 | Coker et al. |
| 7,150,036 | B1 | 12/2006 | Milne et al. |
| 7,155,616 | B1 | 12/2006 | Hamlin |
| 7,171,108 | B1 | 1/2007 | Masters et al. |
| 7,171,110 | B1 | 1/2007 | Wilshire |
| 7,194,576 | B1 | 3/2007 | Boyle |
| 7,200,698 | B1 | 4/2007 | Rothberg |
| 7,205,805 | B1 | 4/2007 | Bennett |
| 7,206,497 | B1 | 4/2007 | Boyle et al. |
| 7,215,496 | B1 | 5/2007 | Kupferman et al. |
| 7,215,771 | B1 | 5/2007 | Hamlin |
| 7,237,054 | B1 | 6/2007 | Cain et al. |
| 7,240,161 | B1 | 7/2007 | Boyle |
| 7,249,365 | B1 | 7/2007 | Price et al. |
| 7,263,709 | B1 | 8/2007 | Krapf |
| 7,274,639 | B1 | 9/2007 | Codilian et al. |
| 7,274,659 | B2 | 9/2007 | Hospodor |
| 7,275,116 | B1 | 9/2007 | Hanmann et al. |
| 7,280,302 | B1 | 10/2007 | Masiewicz |
| 7,292,774 | B1 | 11/2007 | Masters et al. |
| 7,292,775 | B1 | 11/2007 | Boyle et al. |
| 7,296,284 | B1 | 11/2007 | Price et al. |
| 7,302,501 | B1 | 11/2007 | Cain et al. |
| 7,302,579 | B1 | 11/2007 | Cain et al. |
| 7,318,088 | B1 | 1/2008 | Mann |
| 7,319,806 | B1 | 1/2008 | Willner et al. |
| 7,325,244 | B2 | 1/2008 | Boyle et al. |
| 7,330,323 | B1 | 2/2008 | Singh et al. |
| 7,346,790 | B1 | 3/2008 | Klein |
| 7,366,641 | B1 | 4/2008 | Masiewicz et al. |
| 7,369,340 | B1 | 5/2008 | Dang et al. |
| 7,369,343 | B1 | 5/2008 | Yeo et al. |
| 7,372,650 | B1 | 5/2008 | Kupferman |
| 7,380,147 | B1 | 5/2008 | Sun |
| 7,392,340 | B1 | 6/2008 | Dang et al. |
| 7,404,013 | B1 | 7/2008 | Masiewicz |
| 7,406,545 | B1 | 7/2008 | Rothberg et al. |
| 7,415,571 | B1 | 8/2008 | Hanan |
| 7,436,610 | B1 | 10/2008 | Thelin |
| 7,437,502 | B1 | 10/2008 | Coker |
| 7,440,214 | B1 | 10/2008 | Ell et al. |
| 7,451,344 | B1 | 11/2008 | Rothberg |
| 7,471,483 | B1 | 12/2008 | Ferris et al. |
| 7,471,486 | B1 | 12/2008 | Coker et al. |
| 7,486,060 | B1 | 2/2009 | Bennett |
| 7,496,493 | B1 | 2/2009 | Stevens |
| 7,518,819 | B1 | 4/2009 | Yu et al. |
| 7,526,184 | B1 | 4/2009 | Parkinen et al. |
| 7,539,924 | B1 | 5/2009 | Vasquez et al. |
| 7,543,117 | B1 | 6/2009 | Hanan |
| 7,551,383 | B1 | 6/2009 | Kupferman |
| 7,562,282 | B1 | 7/2009 | Rothberg |
| 7,577,973 | B1 | 8/2009 | Kapner, III et al. |
| 7,596,797 | B1 | 9/2009 | Kapner, III et al. |
| 7,599,139 | B1 | 10/2009 | Bombet et al. |
| 7,619,841 | B1 | 11/2009 | Kupferman |
| 7,647,544 | B1 | 1/2010 | Masiewicz |
| 7,649,704 | B1 | 1/2010 | Bombet et al. |
| 7,653,927 | B1 | 1/2010 | Kapner, III et al. |
| 7,656,603 | B1 | 2/2010 | Xing |
| 7,656,763 | B1 | 2/2010 | Jin et al. |
| 7,657,149 | B2 | 2/2010 | Boyle |
| 7,672,072 | B1 | 3/2010 | Boyle et al. |
| 7,673,075 | B1 | 3/2010 | Masiewicz |
| 7,688,540 | B1 | 3/2010 | Mei et al. |
| 7,724,461 | B1 | 5/2010 | McFadyen et al. |
| 7,725,584 | B1 | 5/2010 | Hanmann et al. |
| 7,730,295 | B1 | 6/2010 | Lee |
| 7,760,458 | B1 | 7/2010 | Trinh |
| 7,768,776 | B1 | 8/2010 | Szeremeta et al. |
| 7,804,657 | B1 | 9/2010 | Hogg et al. |
| 7,813,954 | B1 | 10/2010 | Price et al. |
| 7,827,320 | B1 | 11/2010 | Stevens |
| 7,839,588 | B1 | 11/2010 | Dang et al. |
| 7,843,660 | B1 | 11/2010 | Yeo |
| 7,852,596 | B2 | 12/2010 | Boyle et al. |
| 7,859,782 | B1 | 12/2010 | Lee |
| 7,872,822 | B1 | 1/2011 | Rothberg |
| 7,898,756 | B1 | 3/2011 | Wang |
| 7,898,762 | B1 | 3/2011 | Guo et al. |
| 7,900,037 | B1 | 3/2011 | Fallone et al. |
| 7,907,364 | B2 | 3/2011 | Boyle et al. |
| 7,929,234 | B1 | 4/2011 | Boyle et al. |
| 7,933,087 | B1 | 4/2011 | Tsai et al. |
| 7,933,090 | B1 | 4/2011 | Jung et al. |
| 7,934,030 | B1 | 4/2011 | Sargenti, Jr. et al. |
| 7,940,491 | B2 | 5/2011 | Szeremeta et al. |
| 7,944,639 | B1 | 5/2011 | Wang |
| 7,945,727 | B2 | 5/2011 | Rothberg et al. |
| 7,949,564 | B1 | 5/2011 | Hughes et al. |
| 7,974,029 | B2 | 7/2011 | Tsai et al. |
| 7,974,039 | B1 | 7/2011 | Xu et al. |
| 7,982,993 | B1 | 7/2011 | Tsai et al. |
| 7,984,200 | B1 | 7/2011 | Bombet et al. |
| 7,990,647 | B2 | 8/2011 | Lille |
| 7,990,648 | B1 | 8/2011 | Wang |
| 7,992,179 | B1 | 8/2011 | Kapner, III et al. |
| 8,004,785 | B1 | 8/2011 | Tsai et al. |
| 8,006,027 | B1 | 8/2011 | Stevens et al. |
| 8,014,094 | B1 | 9/2011 | Jin |
| 8,014,977 | B1 | 9/2011 | Masiewicz et al. |
| 8,019,914 | B1 | 9/2011 | Vasquez et al. |
| 8,040,625 | B1 | 10/2011 | Boyle et al. |
| 8,078,943 | B1 | 12/2011 | Lee |
| 8,079,045 | B2 | 12/2011 | Krapf et al. |
| 8,082,433 | B1 | 12/2011 | Fallone et al. |
| 8,085,487 | B1 | 12/2011 | Jung et al. |
| 8,089,719 | B1 | 1/2012 | Dakroub |
| 8,090,902 | B1 | 1/2012 | Bennett et al. |
| 8,090,906 | B1 | 1/2012 | Blaha et al. |
| 8,091,112 | B1 | 1/2012 | Elliott et al. |
| 8,094,396 | B1 | 1/2012 | Zhang et al. |
| 8,094,401 | B1 | 1/2012 | Peng et al. |
| 8,116,020 | B1 | 2/2012 | Lee |

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,116,025 B1 2/2012 Chan et al.
8,134,793 B1 3/2012 Vasquez et al.
8,134,798 B1 3/2012 Thelin et al.
8,139,301 B1 3/2012 Li et al.
8,139,310 B1 3/2012 Hogg
8,144,419 B1 3/2012 Liu
8,145,452 B1 3/2012 Masiewicz et al.
8,149,528 B1 4/2012 Suratman et al.
8,154,812 B1 4/2012 Boyle et al.
8,159,768 B1 4/2012 Miyamura
8,161,328 B1 4/2012 Wilshire
8,164,849 B1 4/2012 Szeremeta et al.
8,174,780 B1 5/2012 Tsai et al.
8,190,575 B1 5/2012 Ong et al.
8,194,338 B1 6/2012 Zhang
8,194,340 B1 6/2012 Boyle et al.
8,194,341 B1 6/2012 Boyle
8,201,066 B1 6/2012 Wang
8,271,692 B1 9/2012 Dinh et al.
8,279,550 B1 10/2012 Hogg
8,281,218 B1 10/2012 Ybarra et al.
8,285,923 B2 10/2012 Stevens
8,289,656 B1 10/2012 Huber
8,305,705 B1 11/2012 Roohr
8,307,156 B1 11/2012 Codilian et al.
8,310,775 B1 11/2012 Boguslawski et al.
8,315,006 B1 11/2012 Chahwan et al.
8,316,263 B1 11/2012 Gough et al.
8,320,067 B1 11/2012 Tsai et al.
8,324,974 B1 12/2012 Bennett
8,332,695 B2 12/2012 Dalphy et al.
8,339,919 B1 12/2012 Lee
8,341,337 B1 12/2012 Ong et al.
8,350,628 B1 1/2013 Bennett
8,356,184 B1 1/2013 Meyer et al.
8,370,683 B1 2/2013 Ryan et al.
8,375,225 B1 2/2013 Ybarra
8,375,274 B1 2/2013 Bonke
8,380,922 B1 2/2013 DeForest et al.
8,390,948 B2 3/2013 Hogg
8,390,952 B1 3/2013 Szeremeta
8,392,689 B1 3/2013 Lott
8,407,393 B1 3/2013 Yolar et al.
8,413,010 B1 4/2013 Vasquez et al.
8,417,566 B2 4/2013 Price et al.
8,421,663 B1 4/2013 Bennett
8,422,172 B1 4/2013 Dakroub et al.
8,427,770 B1 4/2013 O'Dell et al.
8,427,771 B1 4/2013 Tsai
8,429,343 B1 4/2013 Tsai
8,433,937 B1 4/2013 Wheelock et al.
8,433,977 B1 4/2013 Vasquez et al.
8,441,909 B1 5/2013 Thayamballi et al.
8,456,643 B2 6/2013 Prabhakaran et al.
8,456,980 B1 6/2013 Thayamballi
8,458,526 B2 6/2013 Dalphy et al.
8,462,466 B2 6/2013 Huber
8,467,151 B1 6/2013 Huber
8,483,027 B1 7/2013 Mak et al.
8,489,841 B1 7/2013 Strecke et al.
8,493,679 B1 7/2013 Boguslawski et al.
8,499,198 B1 7/2013 Messenger et al.
8,514,506 B1 8/2013 Li et al.
8,554,741 B1 10/2013 Malina
8,560,759 B1 10/2013 Boyle et al.
8,576,509 B1 11/2013 Hogg
8,576,511 B1 11/2013 Coker et al.
8,578,100 B1 11/2013 Huynh et al.
8,578,242 B1 11/2013 Burton et al.
8,582,223 B1 11/2013 Garani et al.
8,582,231 B1 11/2013 Kermiche et al.
8,589,773 B1 11/2013 Wang et al.
8,593,753 B1 11/2013 Anderson
8,599,512 B2 12/2013 Hogg
8,605,379 B1 12/2013 Sun
8,611,031 B1 12/2013 Tan et al.
8,611,032 B2 12/2013 Champion et al.
8,612,798 B1 12/2013 Tsai
8,619,383 B1 12/2013 Jung et al.
8,619,508 B1 12/2013 Krichevsky et al.
8,619,529 B1 12/2013 Liew et al.
8,621,115 B1 12/2013 Bombet et al.
8,621,133 B1 12/2013 Boyle
8,625,224 B1 1/2014 Lin et al.
8,625,225 B1 1/2014 Wang
8,626,463 B2 1/2014 Stevens et al.
8,630,052 B1 1/2014 Jung et al.
8,631,188 B1 1/2014 Heath et al.
8,635,412 B1 1/2014 Wilshire
8,661,193 B1 2/2014 Cobos et al.
8,665,547 B1 3/2014 Yeo et al.
8,667,248 B1 3/2014 Neppalli
8,670,205 B1 3/2014 Malina et al.
8,671,250 B2 3/2014 Lee
8,681,442 B2 3/2014 Hogg
8,681,445 B1 3/2014 Kermiche et al.
8,683,295 B1 3/2014 Syu et al.
8,687,306 B1 4/2014 Coker et al.
8,687,307 B1 4/2014 Patton, III
8,687,313 B2 4/2014 Selvaraj
8,693,133 B1 4/2014 Lee et al.
8,698,492 B1 4/2014 Mak et al.
8,699,171 B1 4/2014 Boyle
8,699,172 B1 4/2014 Gunderson et al.
8,711,500 B1 4/2014 Fong et al.
8,711,506 B1 4/2014 Giovenzana et al.
8,711,665 B1 4/2014 Abdul Hamid
8,717,694 B1 5/2014 Liew et al.
8,717,695 B1 5/2014 Lin et al.
8,730,612 B1 5/2014 Haralson
8,743,502 B1 6/2014 Bonke et al.
8,743,667 B1 6/2014 Brockie et al.
8,749,911 B1 6/2014 Sun et al.
8,753,146 B1 6/2014 Szeremeta et al.
8,755,136 B1 6/2014 Ng et al.
8,756,361 B1 6/2014 Carlson et al.
8,760,782 B1 6/2014 Garani et al.
8,760,792 B1 6/2014 Tam
8,769,593 B1 7/2014 Schwartz et al.
8,773,793 B1 7/2014 McFadyen
8,773,802 B1 7/2014 Anderson et al.
8,773,807 B1 7/2014 Chia et al.
8,773,957 B1 7/2014 Champion et al.
8,780,470 B1 7/2014 Wang et al.
8,782,334 B1 7/2014 Boyle et al.
8,786,976 B1 7/2014 Kang et al.
8,787,125 B1 7/2014 Lee
8,792,196 B1 7/2014 Lee
8,792,200 B1 7/2014 Tam et al.
8,797,667 B1 8/2014 Barlow et al.
8,799,977 B1 8/2014 Kapner, III et al.
8,817,413 B1 8/2014 Knigge et al.
8,817,584 B1 8/2014 Selvaraj
8,825,976 B1 9/2014 Jones
8,825,977 B1 9/2014 Syu et al.
8,897,104 B1 11/2014 Yan et al.
8,902,718 B1 12/2014 Ruan et al.
8,976,633 B1 3/2015 Ruan et al.
2007/0230012 A1 10/2007 Erden et al.
2007/0291401 A1* 12/2007 Sun ........................ G11B 5/596 360/75
2009/0113702 A1 5/2009 Hogg
2009/0207519 A1 8/2009 Erden et al.
2010/0123967 A1 5/2010 Batra et al.
2010/0306551 A1 12/2010 Meyer et al.
2011/0188361 A1* 8/2011 Fuse .................... G11B 7/1267 369/47.51
2011/0205861 A1* 8/2011 Erden ...................... G11B 5/02 369/13.27
2011/0226729 A1 9/2011 Hogg
2011/0228652 A1* 9/2011 Gage ...................... G11B 5/314 369/13.26
2012/0159042 A1 6/2012 Lott et al.
2012/0275050 A1 11/2012 Wilson et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| 2012/0281963 | A1 | 11/2012 | Krapf et al. |
| 2012/0324980 | A1 | 12/2012 | Nguyen et al. |
| 2013/0094104 | A1 | 4/2013 | Ngan et al. |

OTHER PUBLICATIONS

Galvin T. Chia, et al., U.S. Appl. No. 14/483,397, filed Sep. 11, 2014, 21 pages.

* cited by examiner

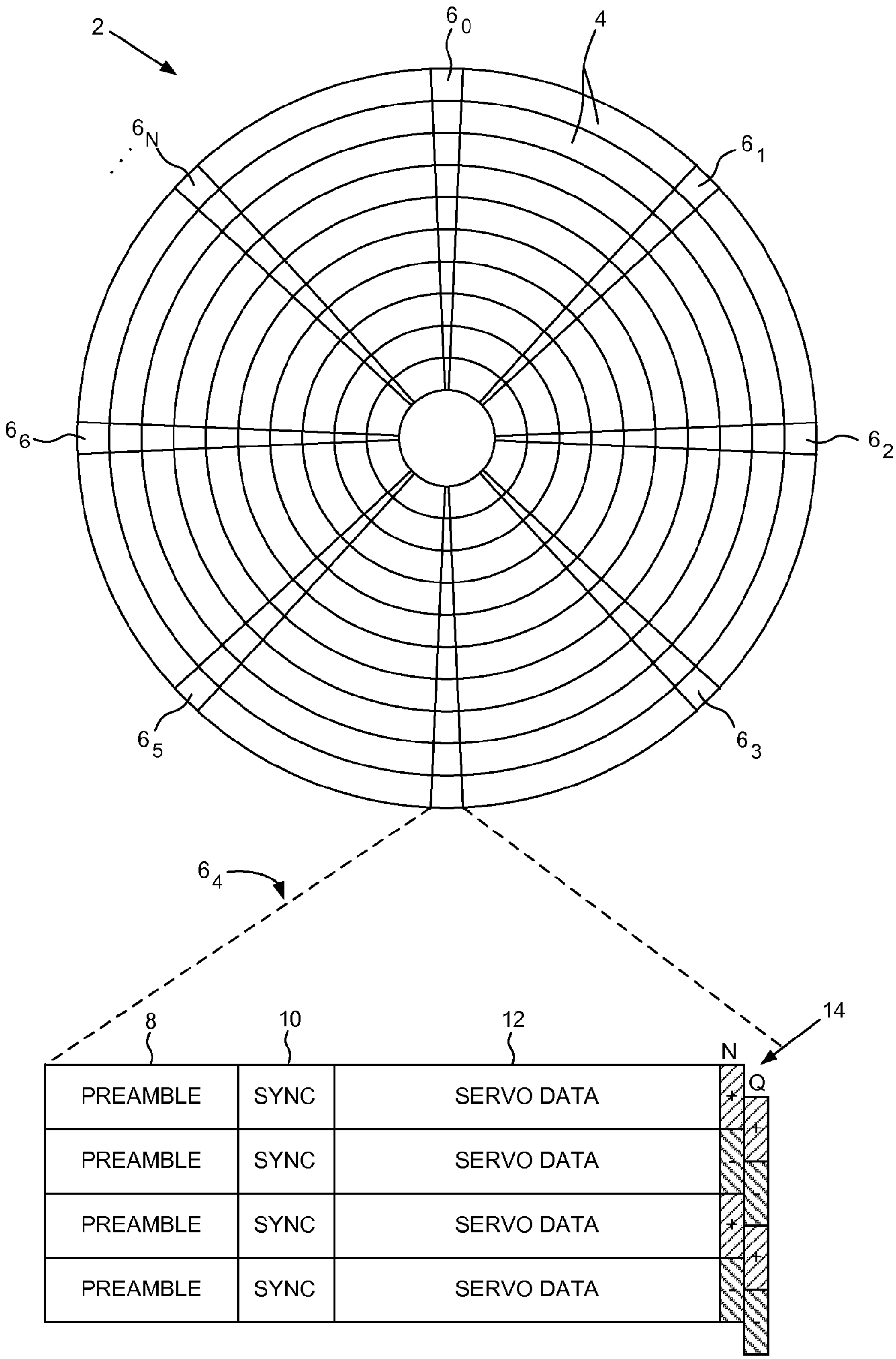



FIG. 1
(Prior Art)

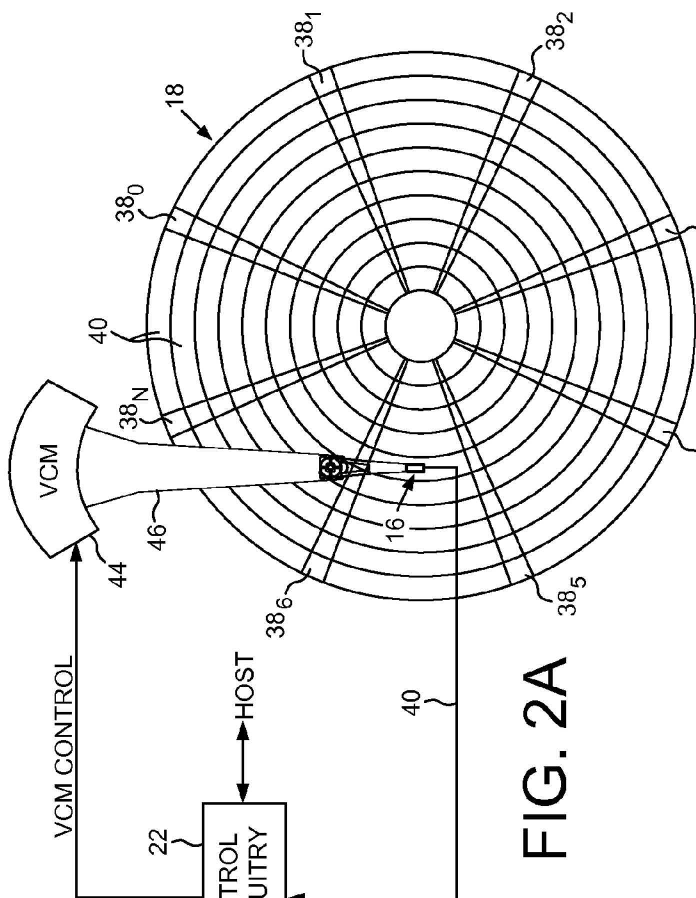



FIG. 2A

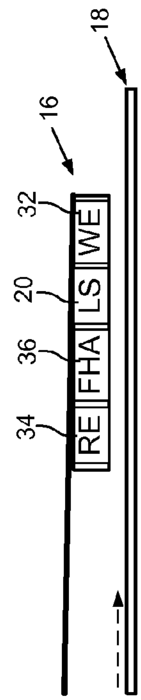



FIG. 2B

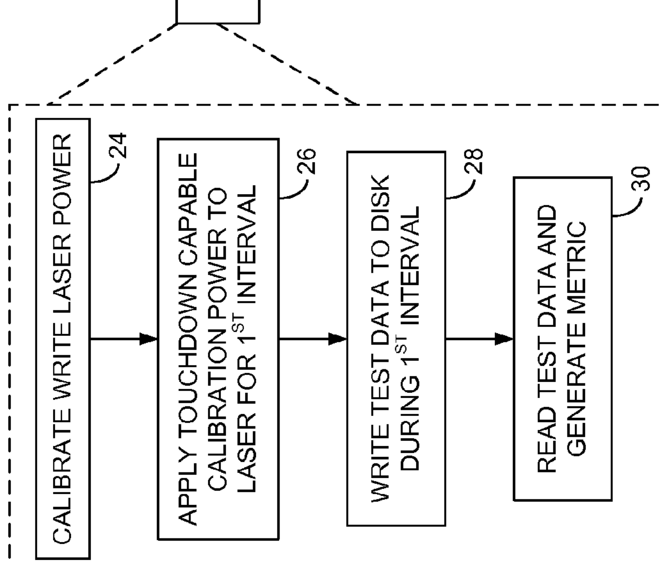



FIG. 2C

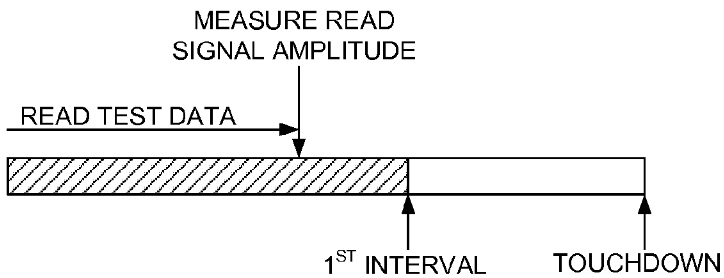

MEASURE READ
SIGNAL AMPLITUDE
READ TEST DATA
1ST INTERVAL
TOUCHDOWN

FIG. 3A

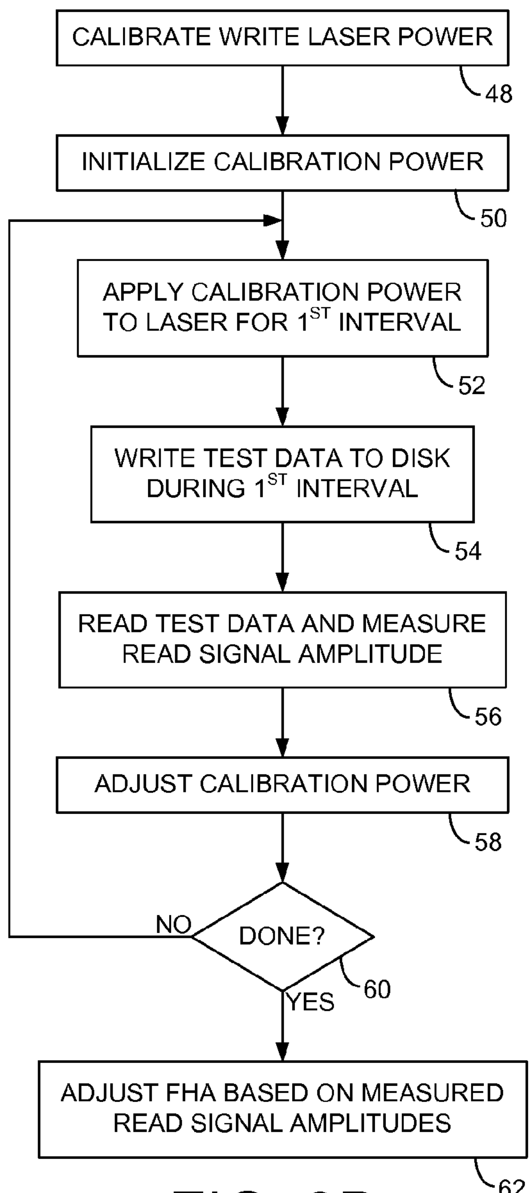

CALIBRATE WRITE LASER POWER
48
INITIALIZE CALIBRATION POWER
50
APPLY CALIBRATION POWER TO LASER FOR 1ST INTERVAL
52
WRITE TEST DATA TO DISK DURING 1ST INTERVAL
54
READ TEST DATA AND MEASURE READ SIGNAL AMPLITUDE
56
ADJUST CALIBRATION POWER
58
DONE?
NO
YES
60
ADJUST FHA BASED ON MEASURED READ SIGNAL AMPLITUDES
62

FIG. 3B

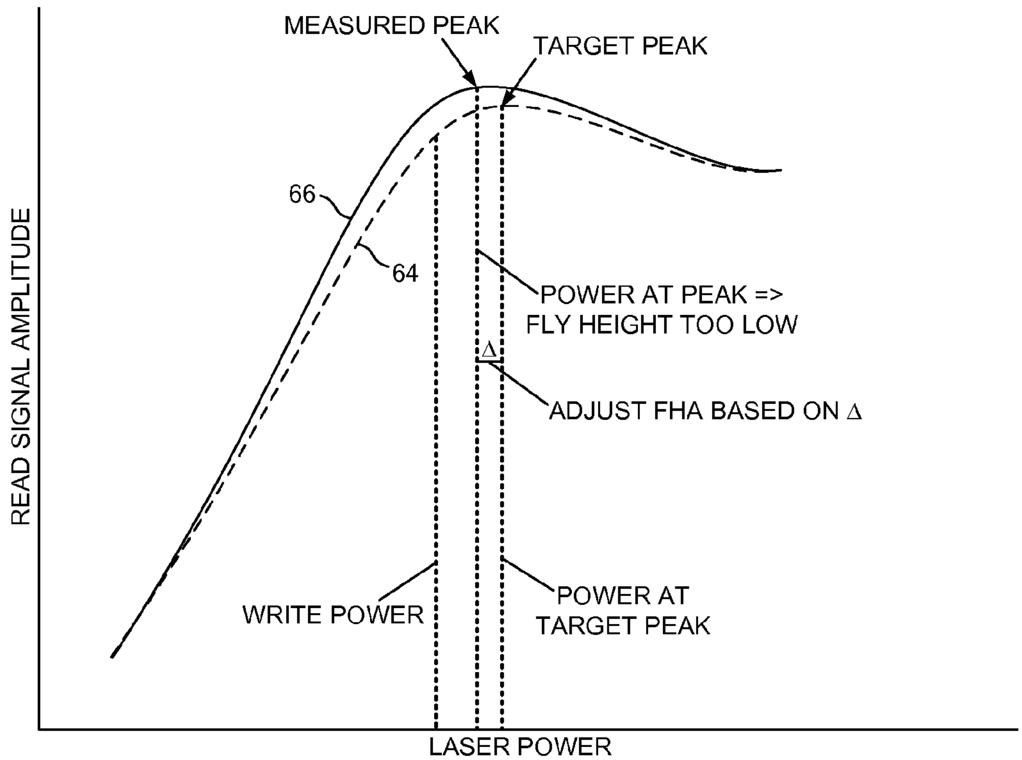

MEASURED PEAK
TARGET PEAK
66
64
POWER AT PEAK =>
FLY HEIGHT TOO LOW
Δ
ADJUST FHA BASED ON Δ
READ SIGNAL AMPLITUDE
WRITE POWER
POWER AT
TARGET PEAK
LASER POWER

FIG 4A

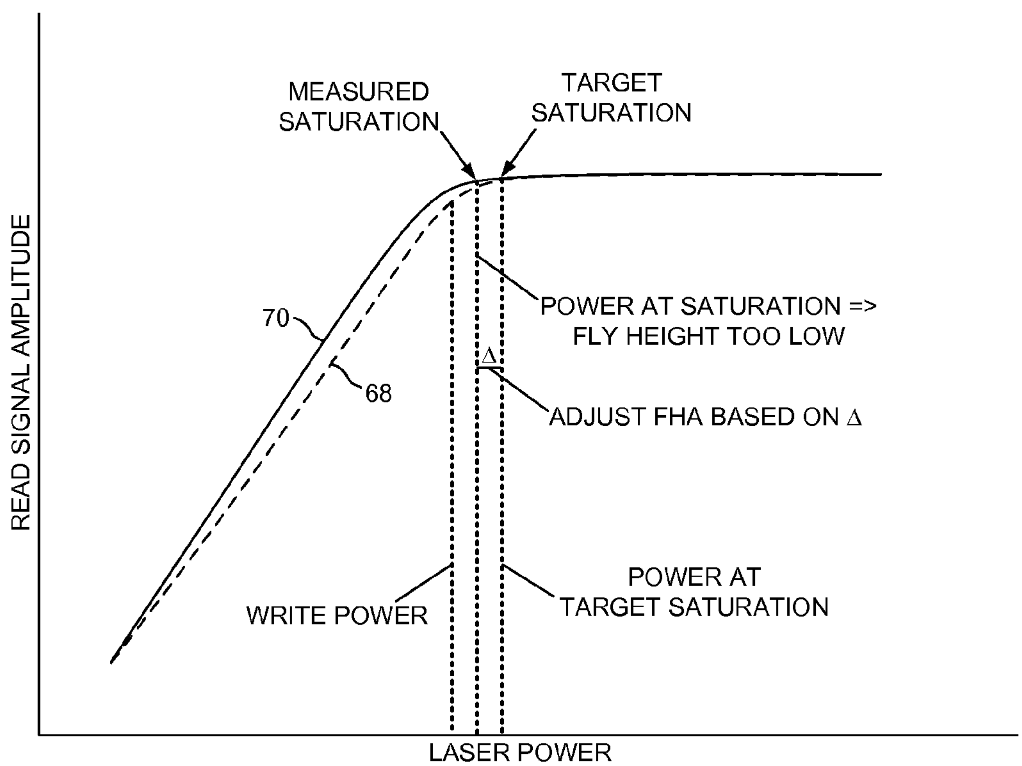

MEASURED
SATURATION
TARGET
SATURATION
70
68
POWER AT SATURATION =>
FLY HEIGHT TOO LOW
Δ
ADJUST FHA BASED ON Δ
READ SIGNAL AMPLITUDE
WRITE POWER
POWER AT
TARGET SATURATION
LASER POWER

FIG 4B

# DATA STORAGE DEVICE CALIBRATING PARAMETER FOR HEAT ASSISTED MAGNETIC RECORDING

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to provisional U.S. Patent Application Ser. No. 62/156,136, filed on May 1, 2015, which is hereby incorporated by reference in its entirety.

## BACKGROUND

Data storage devices such as disk drives may comprise a disk and a head connected to a distal end of an actuator arm which is rotated about a pivot by a voice coil motor (VCM) to position the head radially over the disk. The disk comprises a plurality of radially spaced, concentric tracks for recording user data sectors and embedded servo sectors. The embedded servo sectors comprise head positioning information (e.g., a track address) which is read by the head and processed by a servo controller to control the actuator arm as it seeks from track to track.

Data is typically written to the disk by modulating a write current in an inductive coil to record magnetic transitions onto the disk surface in a process referred to as saturation recording. During readback, the magnetic transitions are sensed by a read element (e.g., a magnetoresistive element) and the resulting read signal demodulated by a suitable read channel. Heat assisted magnetic recording (HAMR) is a recent development that improves the quality of written data by heating the disk surface with a laser during write operations in order to decrease the coercivity of the magnetic medium, thereby enabling the magnetic field generated by the write coil to more readily magnetize the disk surface.

FIG. **1** shows a prior art disk format **2** as comprising a number of servo tracks **4** defined by servo sectors $\mathbf{6}_0$-$\mathbf{6}_N$ recorded around the circumference of each servo track. Each servo sector $\mathbf{6}_i$ comprises a preamble **8** for storing a periodic pattern, which allows proper gain adjustment and timing synchronization of the read signal, and a sync mark **10** for storing a special pattern used to symbol synchronize to a servo data field **12**. The servo data field **12** stores coarse head positioning information, such as a servo track address, used to position the head over a target data track during a seek operation. Each servo sector $\mathbf{6}_i$ further comprises groups of servo bursts **14** (e.g., N and Q servo bursts), which are recorded with a predetermined phase relative to one another and relative to the servo track centerlines. The phase based servo bursts **14** provide fine head position information used for centerline tracking while accessing a data track during write/read operations. A position error signal (PES) is generated by reading the servo bursts **14**, wherein the PES represents a measured position of the head relative to a centerline of a target servo track. A servo controller processes the PES to generate a control signal applied to a head actuator (e.g., a voice coil motor) in order to actuate the head radially over the disk in a direction that reduces the PES.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a prior art disk format comprising a plurality of servo tracks defined by servo sectors.

FIG. **2**A shows a data storage device in the form of a disk drive according to an embodiment comprising a head actuated over a disk.

FIG. **2**B shows a head according to an embodiment comprising a laser configured to heat the disk while writing data to the disk and a fly height actuator configured to actuate the head vertically over the disk.

FIG. **2**C is a flow diagram according to an embodiment wherein during a calibration procedure a touchdown capable calibration power is applied to the laser for a first interval too short to cause the head to contact the disk.

FIG. **3**A illustrates an embodiment wherein test data is written to the disk while applying the calibration power to the laser during the first interval, wherein the head would eventually contact the disk if the calibration power were applied to the laser for a second interval longer than the first interval.

FIG. **3**B is a flow diagram according to an embodiment wherein test data is written to and read form the disk over a number of different calibration powers to generate a plurality of metrics, and a control signal applied to the fly height actuator is adjusted based on the metrics.

FIG. **4**A illustrates an embodiment wherein the control signal applied to the fly height actuator is adjusted based on a difference between a measured peak in the metrics and a target peak.

FIG. **4**B illustrates an embodiment wherein the control signal applied to the fly height actuator is adjusted based on a difference between a measured saturation in the metrics and a target saturation.

## DETAILED DESCRIPTION

FIG. **2**A shows a data storage device in the form of a disk drive according to an embodiment comprising a head **16** actuated over a disk **18**, wherein the head **16** (FIG. **2**B) comprises a laser **20** configured to heat the disk **18** while writing data to the disk **18**. The disk drive further comprises control circuitry **22** configured to execute the flow diagram of FIG. **2**C, wherein a write power for the laser is calibrated and applied to the laser while writing user data to the disk (block **24**). A calibration power is applied to the laser for a first interval, wherein the calibration power is high enough to cause the head to contact the disk if applied for a second interval longer than the first interval (block **26**). While applying the calibration power to the laser, test data is written to the disk during at least part of the first interval (block **28**). The test data is read from the disk to generate a read signal, and a metric is generated based on the read signal (block **30**).

In the embodiment of FIG. **2**B, the head **16** comprises a suitable write element **32** (e.g., an inductive coil), a suitable read element **34** (e.g., a magnetoresistive element), and a suitable fly height actuator (FHA) **36** configured to actuate the head **16** vertically over the disk **18**. Any suitable FHA **36** may be employed, such as a heater that actuates through thermal expansion, or a piezoelectric actuator that actuates through mechanical deflection.

In the embodiment of FIG. **2**A, servo sectors $\mathbf{38}_0$-$\mathbf{38}_N$ define a plurality of servo tracks **30**, wherein data tracks are defined relative to the servo tracks at the same or different radial density. In an embodiment where the servo sectors $\mathbf{38}_0$-$\mathbf{38}_N$ are recorded at the same data rate, the servo sectors $\mathbf{38}_0$-$\mathbf{38}_N$ form servo wedges that extend radially across the disk **18** as shown in FIG. **2**A. Other embodiments may employ zoned servo sectors wherein the data rate may vary across the radius of the disk, thereby forming servo wedges within each servo zone. The control circuitry **22** processes a read signal **40** emanating from the head **16** to demodulate the servo sectors $\mathbf{38}_0$-$\mathbf{38}_N$ and generate a position error signal

(PES) representing an error between the actual position of the head and a target position relative to a target track. The control circuitry **22** filters the PES using a suitable compensation filter to generate a control signal **42** applied to a voice coil motor (VCM) **44** which rotates an actuator arm **46** about a pivot in order to actuate the head **16** radially over the disk **18** in a direction that reduces the PES. The servo sectors $\mathbf{38}_0$-$\mathbf{38}_N$ may comprise any suitable head position information, such as a track address for coarse positioning and servo bursts for fine positioning. The servo bursts may comprise any suitable pattern, such as an amplitude based servo pattern or a phase based servo pattern (e.g., as shown in FIG. **1**).

In one embodiment, it may be desirable to calibrate one or more parameters that affect the quality of the recorded data, and the therefore the accuracy in recovering the recorded data. For example, in one embodiment the quality of the recorded data may depend on the fly height of the head **16** over the disk **18** when writing the data. The fly height may affect the efficacy of the laser **20** to heat the surface of the disk **18** while maintaining a target track width (and corresponding density) for the data tracks. Accordingly, in one embodiment a control signal applied to the FHA **36** (FIG. **2**B) may be calibrated in order to achieve a target fly height during write operations. In some embodiments, certain environmental conditions, such as the ambient temperature, or other factors (such as degradation of the laser), may affect the fly height of the head **16** over time. In one embodiment, it may be desirable to detect when the fly height of the head **16** has deviated from the target fly height so that the control signal applied to the FHA may be adjusted and/or so that the write power for the laser may be adjusted.

In one embodiment, a calibration power may be applied to the laser **20** during a calibration procedure, wherein during a first interval test data may be written to a target data track such as shown in FIG. **3**A. At the end of the first interval, the writing of the test data terminates and the power applied to the laser is reduced in order to avoid the head **16** contacting the disk **18**. That is, in one embodiment the calibration power applied to the laser **20** is high enough such that the thermal protrusion of the head components over time (i.e., for a second interval longer than the first interval) would eventually cause the head **16** to contact the disk **18** as illustrated in FIG. **3**A. The test data is then read from the disk **18** to generate a suitable metric based on the read signal. For example, in one embodiment the metric may comprise the amplitude of the read signal after reading at least part of the test data as illustrated in FIG. **3**A. In one embodiment, the process of writing/reading the test pattern may be repeated at different calibration power levels and a corresponding metric generated at each calibration power level. The resulting metrics may then be evaluated to calibrate a parameter of the disk drive, such as the control signal applied to the FHA **36** in order to maintain a target fly height of the head during write operations.

An example of this embodiment is understood with reference to the flow diagram of FIG. **3**B in view of the read signal amplitude waveforms shown in FIGS. **4**A and **4**B. After calibrating the write power for the laser (block **48**), the calibration power for the laser is initialized to a value different than the write power, such as less than the write power (block **50**). While applying the calibration power to the laser for a first interval (block **52**), test data is written to the disk during at least part of a first interval (block **54**). The test data is then read to generate a read signal, and the amplitude of the read signal after reading at least part of the test data is measured and saved (block **56**). The calibration power is then adjusted (block **58**), such as by increasing the calibration power, and the process is repeated from block **52** until a sufficient number of read signal amplitude measurements have been taken (block **60**). The control signal applied to the FHA is then adjusted based on the saved read signal amplitudes (block **62**).

Referring to the example shown in FIG. **4**A, the dashed waveform **64** may represent the read signal amplitude described above measured by reading the test data from the disk written using different calibration power levels. When the calibration power applied to the laser is low, the read signal amplitude is low due to an undersaturation of the media. As the calibration power increases, the read signal amplitude increases, and as shown in the example embodiment of FIG. **4**A, the read signal amplitude may eventually reach a peak at a calibration power that is greater than the write power for the laser (i.e., the write power calibrated for normal write operations). In the embodiment of FIG. **4**A, the read signal amplitude begins to decrease as the calibration power applied to the laser is further increased. As the calibration power is increased past the write power, the calibration power will reach a level that will cause the head to contact the disk if applied to the laser for too long (past the first interval) as described above. Accordingly, in one embodiment the first interval is selected to ensure the head **16** will not contact the disk **18** while enabling the test data to be written at higher laser powers so that the desired metric (e.g., read signal amplitude) may be measured.

In one embodiment, at least part of the dashed waveform **64** shown in FIG. **4**A may be generated by executing the flow diagram of FIG. **3**B after calibrating the control signal applied to the FHA to achieve the target fly height as well as calibrating the write power for the laser. In this manner the peak in the dashed waveform **64** may correspond to a target inflection point when the head **16** is flying over the disk **18** at the target fly height during write operations. In one embodiment, the flow diagram of FIG. **3**B may be re-executed periodically or reactively in order to verify that the head is still flying at the target fly height during write operations. For example, in some embodiments the control circuitry may react to a temperature sensor, or to a quality metric associated with the read signal, when deciding whether to re-execute the flow diagram of FIG. **3**B. In one embodiment, the control circuitry may seek the head to a calibration track in order to re-execute the flow diagram of FIG. **3**B so that previously recorded user data is not overwritten by the test data.

The solid waveform **66** in FIG. **4**A shows an embodiment wherein the inflection point (measured peak in this example) that is generated after re-executing the flow diagram of FIG. **3**B shifts left from the target inflection point (target peak in this example) due to the head flying too low. That is, the calibrated power corresponding to the measured peak in waveform **66** occurs at a lower power than the calibrated power corresponding to the target peak in waveform **64**. In one embodiment, the difference in the calibration powers (i.e., the delta) may be processed in order to adjust the control signal applied to the FHA **36**. Alternatively, the delta exceeding a threshold may trigger a recalibration of the control signal applied to the FHA **36** using any suitable technique.

In another embodiment, the amplitude of the read signal at the measured peak in the waveform **66** may deviate from the amplitude at the target peak in the target waveform **64** as shown in the example of FIG. **4**A. Accordingly, in one embodiment the difference in the read signal amplitude at the measured peak relative to the target peak may be used to adjust the control signal applied to the FHA **36** or trigger a recalibration of the control signal.

FIG. **4**B illustrates another embodiment wherein the read signal amplitude waveforms (e.g., target waveform **68** and deviant waveform **70**) may exhibit an inflection point other than a peak. In this example, the inflection point comprises a saturation point of the read signal amplitude which may be measured in any suitable manner, such as by measuring when the slope of the read signal amplitude approaches zero. Accordingly in this embodiment the control signal applied to the FHA **36** may be adjusted, or a recalibration of the control signal triggered, based on the delta between the target saturation point and the measured saturation point after re-executing the flow diagram of FIG. **3**B.

In one embodiment, the metric generated at block **30** of FIG. **2**C may be used to adjust the write power for the laser, or may be used to trigger a recalibration of the write power using any suitable technique. That is, in one embodiment the deviation in the inflection point such as shown in the examples of FIGS. **4**A and **4**B may be compensated by adjusting the write power applied to the laser instead of, or in addition to, adjusting the control signal applied to the FHA **36**. For example, if a change in the ambient temperature causes the head to deviate from the target fly height, it may be desirable to adjust the physical fly height of the head (by adjusting the control signal applied to the FHA **36**) to maintain the target fly height as well as adjust the write power for the laser since the ambient temperature may also affect the output power of the laser. Accordingly, in one embodiment the control circuitry may be configured to adjust (or recalibrate) the write power for the laser after adjusting the control signal applied to the fly height actuator.

The metric generated at block **30** of FIG. **2**C may be used for any suitable reason, such as to adjust the control signal applied to a FHA **36** and thereby adjust the fly height of the head **16** as described above. In one embodiment, one or more other parameters may be adjusted instead of, or in addition to, the control signal applied to the FHA **26**. For example, the write current applied to the write element **32** (FIG. **2**B) may affect the fly height of the head **16** and therefore in one embodiment the write current may be adjusted in response to the metric generated at block **30** of FIG. **2**C. In yet another embodiment, the metric may be used to calibrate the write power for the laser **20** or the write current for the write element **32**. In other embodiments, the metric generated at block **30** of FIG. **2**C may be evaluated to characterize the performance of the laser **20** for quality control and/or to provide feedback to improve the fabrication process for the head **16**.

Any suitable control circuitry may be employed to implement the flow diagrams in the above embodiments, such as any suitable integrated circuit or circuits. For example, the control circuitry may be implemented within a read channel integrated circuit, or in a component separate from the read channel, such as a disk controller, or certain operations described above may be performed by a read channel and others by a disk controller. In one embodiment, the read channel and disk controller are implemented as separate integrated circuits, and in an alternative embodiment they are fabricated into a single integrated circuit or system on a chip (SOC). In addition, the control circuitry may include a suitable preamp circuit implemented as a separate integrated circuit, integrated into the read channel or disk controller circuit, or integrated into a SOC.

In one embodiment, the control circuitry comprises a microprocessor executing instructions, the instructions being operable to cause the microprocessor to perform the flow diagrams described herein. The instructions may be stored in any computer-readable medium. In one embodiment, they may be stored on a non-volatile semiconductor memory external to the microprocessor, or integrated with the microprocessor in a SOC. In another embodiment, the instructions are stored on the disk and read into a volatile semiconductor memory when the disk drive is powered on. In yet another embodiment, the control circuitry comprises suitable logic circuitry, such as state machine circuitry.

In various embodiments, a disk drive may include a magnetic disk drive, an optical disk drive, etc. In addition, while the above examples concern a disk drive, the various embodiments are not limited to a disk drive and can be applied to other data storage devices and systems, such as magnetic tape drives, solid state drives, hybrid drives, etc. In addition, some embodiments may include electronic devices such as computing devices, data server devices, media content storage devices, etc. that comprise the storage media and/or control circuitry as described above.

The various features and processes described above may be used independently of one another, or may be combined in various ways. All possible combinations and subcombinations are intended to fall within the scope of this disclosure. In addition, certain method, event or process blocks may be omitted in some implementations. The methods and processes described herein are also not limited to any particular sequence, and the blocks or states relating thereto can be performed in other sequences that are appropriate. For example, described tasks or events may be performed in an order other than that specifically disclosed, or multiple may be combined in a single block or state. The example tasks or events may be performed in serial, in parallel, or in some other manner. Tasks or events may be added to or removed from the disclosed example embodiments. The example systems and components described herein may be configured differently than described. For example, elements may be added to, removed from, or rearranged compared to the disclosed example embodiments.

While certain example embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions disclosed herein. Thus, nothing in the foregoing description is intended to imply that any particular feature, characteristic, step, module, or block is necessary or indispensable. Indeed, the novel methods and systems described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein may be made without departing from the spirit of the embodiments disclosed herein.

What is claimed is:

**1**. A data storage device comprising:

a disk;

a head actuated over the disk, wherein the head comprises a laser configured to heat the disk while writing data to the disk; and

control circuitry configured to:

(a) calibrate a write power for the laser, wherein the write power is applied to the laser while writing user data to the disk;

(b) apply a calibration power to the laser for a first interval, wherein the calibration power is high enough to cause the head to contact the disk if applied for a second interval longer than the first interval;

(c) while applying the calibration power to the laser, write test data to the disk during at least part of the first interval; and

(d) read the test data from the disk to generate a read signal and generate a metric based on the read signal.

**2**. The data storage device as recited in claim **1**, wherein the data storage device further comprises a fly height actuator configured to actuate the head vertically over the disk, and the control circuitry is further configured to adjust a control signal applied to the fly height actuator based on the metric.

**3**. The data storage device as recited in claim **2**, wherein the control circuitry is further configured to generate the metric as the amplitude of the read signal after reading at least part of the test data.

**4**. The data storage device as recited in claim **3**, wherein the control circuitry is further configured to:

repeat blocks (b) through (d) for a plurality of different calibration powers; and

adjust the control signal applied to the fly height actuator based on a measured inflection point in the metrics generated for the different calibration powers.

**5**. The data storage device as recited in claim **4**, wherein the control circuitry is further configured to adjust the control signal applied to the fly height actuator based on a difference between the measured inflection point and a target inflection point.

**6**. The data storage device as recited in claim **5**, wherein the control circuitry is further configured to calibrate the target inflection point by:

calibrating a write setting for the control signal applied to the fly height actuator; and

while applying the write setting to the fly height actuator, repeating blocks (b) through (d) for a plurality of different calibration powers.

**7**. The data storage device as recited in claim **2**, wherein the control circuitry is further configured to adjust the write power for the laser based on the metric.

**8**. A method of operating a data storage device, the method comprising:

(a) calibrating a write power for a laser of a head, wherein the write power is applied to the laser while writing user data to a disk;

(b) applying a calibration power to the laser for a first interval, wherein the calibration power is high enough to cause the head to contact the disk if applied for a second interval longer than the first interval;

(c) while applying the calibration power to the laser, writing test data to the disk during at least part of the first interval; and

(d) reading the test data from the disk to generate a read signal and generate a metric based on the read signal.

**9**. The method as recited in claim **8**, further comprising adjusting a control signal applied to a fly height actuator based on the metric, wherein the fly height actuator is configured to actuate the head vertically over the disk.

**10**. The method as recited in claim **9**, further comprising generating the metric as the amplitude of the read signal after reading at least part of the test data.

**11**. The method as recited in claim **10**, further comprising:

repeating blocks (b) through (d) for a plurality of different calibration powers; and

adjusting the control signal applied to the fly height actuator based on a measured inflection point in the metrics generated for the different calibration powers.

**12**. The method as recited in claim **11**, further comprising adjusting the control signal applied to the fly height actuator based on a difference between the measured inflection point and a target inflection point.

**13**. The method as recited in claim **12**, further comprising calibrating the target inflection point by:

calibrating a write setting for the control signal applied to the fly height actuator; and

while applying the write setting to the fly height actuator, repeating blocks (b) through (d) for a plurality of different calibration powers.

**14**. The method as recited in claim **9**, further comprising adjusting the write power for the laser based on the metric.

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